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(PCT Rule 61.2)

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Applicant:

KATZ, Marcos et al

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11 July 2000 (11.07.00)

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NOTIFICATION OF THE RECORDING
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To:

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IMPORTANT NOTIFICATION

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14 September 1999 (14.09.99)

1. The following indications appeared on record concerning:



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the agent



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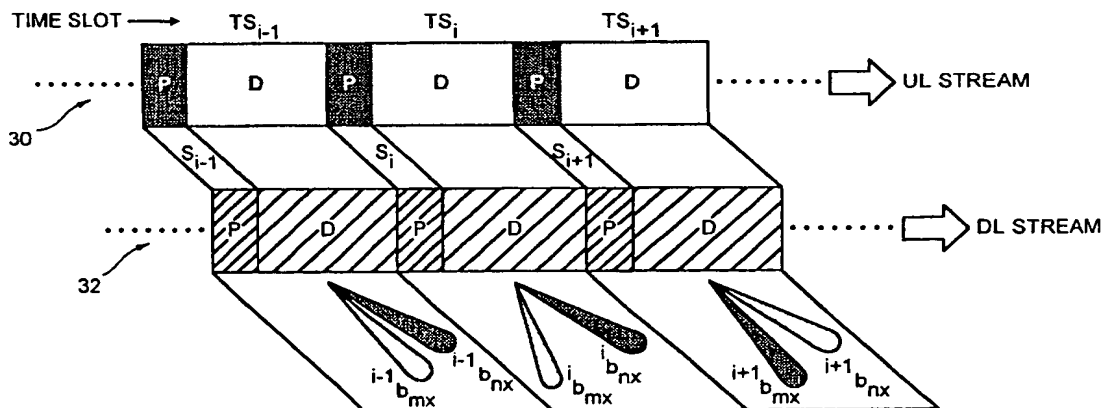
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(54) Title: A METHOD OF DIRECTIONAL RADIO COMMUNICATION



(57) Abstract

A method of directional radio communication between a first station and a second station, the method comprising the steps of defining at the first station a plurality of beam directions available for transmitting successive signals from the first station, selecting at said first station at least one of said directions for transmission of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is such that successive signals or groups of signals are transmitted in substantially different directions and such that on average each beam direction available to said first station is used substantially equally.

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A METHOD OF DIRECTIONAL RADIO COMMUNICATION

5 This invention relates to a method of directional radio communication and in particular, but not exclusively, to a method for use in cellular communication networks using space division multiple access.

10 Cellular communication networks based on space division multiple access and the advantages associated therewith are well known. The area covered by a cellular network is divided into a plurality of cell or cell sectors. Each cell is served by a base station which transmits signals to and receives
15 signals from mobile stations located in the cell or cell sector associated with the respective base station. In a space division multiple access system, the base transceiver station will not transmit signals intended for a given mobile station throughout the cell or cell sector but will only
20 transmit the signal in a beam direction from which a signal from the mobile station is received.

As the beam which is transmitted by the base transceiver station may only be transmitted in a particular direction and
25 accordingly may be relatively narrow, the transmission power is concentrated into that narrow beam. The base station is also able to distinguish the signals received from different directions. This results in a better signal to noise ratio with both the signals transmitted from the base transceiver
30 station and the signals received by the base transceiver station. The interference caused by the signal transmitted by the base station to the mobile station to other mobile stations in the same cell or adjacent cells is also reduced. This increases the capacity of the system and/or increases the
35 quality of communication.

SDMA systems can be implemented in analogue and digital cellular networks and may be incorporated in the various existing standards such as GSM, DCS 1800, TACS, AMPS and NMT.
40 SDMA systems can also be used in conjunction with other existing multiple access techniques based, for example, on

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- 5 time division multiple access (TDMA), code division multiple access (CDMA), such as that described by the US IS-95 CDMA standard and the proposed third generation standard, and frequency division multiple access (FDMA) techniques.
- 10 Signals transmitted from a mobile station to a base transceiver station are known as "uplink" signals and signals transmitted from a base transceiver station to a mobile station are known as "downlink" signals. The uplink communication stream received by the base transceiver station
- 15 from the mobile station comprises a series of communication bursts received in successive time slots. Each received burst of the uplink communication stream includes a reference signal and a data signal.
- 20 Likewise, the downlink communication stream transmitted from the base transceiver station to the mobile station comprises a series of communication bursts transmitted in successive time slots. Each respective burst of the downlink communication stream includes a reference signal and a data
- 25 signal. The reference signals of the uplink and downlink communication streams are, in this example, referred to as pilot signals which are the reference signals in CDMA systems.
- Signals transmitted from base stations should be transmitted
- 30 with enough power to guarantee that the signal received by a particular target mobile station has an acceptable quality while at the same time trying to minimise the effect of that signal on other active mobile stations operating in the same or other sectors.
- 35
- Conventional adaptive base transceiver stations process each communication burst received in the uplink direction to determine transmission parameters for the corresponding burst in the downlink direction. The direction of transmission to
- 40 be used in the downlink communication for a given time slot is determined based on direction of arrival information estimated

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5 from the uplink communication of the corresponding time slot,
the uplink and downlink signals being at different
frequencies.

10 Circuitry within the base transceiver station determines, for
each receive time slot, an angular power profile of the uplink
signal impinging on the base station antenna array from the
mobile station and indicates transmission parameters to be
used in each transmission time slot. In practice, the
15 determined angular power profile is supplied to signal
processing and decision circuitry which executes a beam
selection algorithm to determine the downlink transmission
parameters. Thus, the or each direction of transmission for a
given communication burst, including for the pilot and data
signals within that burst, is determined from estimations of
20 pilot symbols received from the mobile station during the
corresponding uplink communication burst. The selected
transmission parameters are kept fixed for at least the
duration of that burst, i.e. for the entire transmission time
slot.

25 As is known, a signal from a mobile station will generally
follow several paths to the BTS. Those plurality of paths are
generally referred to as multipaths. A given signal which is
transmitted by the mobile station may then be received by the
30 base transceiver station from more than one direction due to
these multipath effects.

In general, the use of beams in more than one downlink
transmission direction leads to a better quality of signal
35 received at the mobile station. One reason for this is that
using a plurality of beams increases the angular diversity and
consequently decreases the signal outage probability.
However, a greater number of beams leads to the generation of
more interference. In certain circumstances, the nature of
40 the generated interference means that even limiting the
transmission to two beam directions does not relieve problems

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5 between co-channel users.

The performance of downlink is measured not only in terms of the quality of signal at the receiving mobile station but also by taking into consideration the use of radio resources and interference to other users resulting from the requirement to achieve that level of quality. The base station aims to achieve at the mobile station a signal quality which is sufficient to produce an acceptable and/or pre-determined quality of service with minimum expenditure of radio resources. Spectral efficiency has a direct impact on system capacity and link performance. Improving link performance will generally require an increase in transmission power or an increased use of radio resources, both of which tend to increase the level of generated interference.

20 This problem worsens in environments characterized by larger angular spreads (e.g., micro- and pico-cells) and also when the angular resolution of base station is increased (e.g., the number of antenna elements is large). The radio channels of indoor environments are typically characterised by small delay and Doppler spreads and large angular spreads. This behaviour results from the rather short base to mobile station distances (the cell is small), the relatively low mobility of the users and the physical environment, and the fact that comparable distances exist between surrounding environment and transmitting and receiving units.

A particular aspect of indoor environments is the simultaneous presence of different kinds of traffic, involving for instance multi-rate services. A common operating scenario will include, for instance, a few high-bit rate users, the rest being basic (speech) users who all operate at the same time. An effective transmission strategy for a base station using adaptive antennae might be to select the most convenient downlink directions of transmission based on estimated uplink directions with high associated power.

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5 In a low mobility environment (e.g. an indoor cell) the physical radio environment will tend to remain unchanged for a considerable amount of time and thus the direction(s) of transmission selected for each mobile station will be kept the same for relatively long periods. In multi-rate environments, this approach can generate undesirably high levels of spatially coloured interference. In other words, the background interference varies across the cell. For example, a base station serving a fixed or slowly moving high bit rate user operating in a pico-cell (i.e. a small cell) will select a few (e.g. two) directions of transmission based on the best received signal paths. In addition, to provide signals to the target high bit rate mobile station, the base station also produces high powered interference in the selected directions. Low bit rate users operating within the corresponding illuminated area will clearly be affected by this cross-correlation type of interference. The degrading effect of the interference is intensified by the fact that interfering signal tends to stay unchanged in the spatial (and delay) domain and consequently no averaging can be exploited by the receiver.

Thus in indoor environments, and in other environments where the angular spread is large and/or the user mobility is low, a conventional base station using adaptive antennas will tend to generate highly coloured interference when transmitting in the downlink direction. The spatial directions employed by high bit rate users tend to contain signals at high levels of transmitted power and thus affect lower bit rate co-channel users.

Embodiments of the present invention seek to provide an improved method for directional radio communication.

According to an aspect of the present invention there is provided a method of directional radio communication between a first station and a second station, the method comprising

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5 the steps of determining at the first station a set of one or more directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station, selecting at said first station at least one of said directions for transmission
10 of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is such that successive signals or groups of signals are transmitted in substantially different directions and such that on average each beam direction available to said
15 first station is used substantially equally.

In one embodiment one beam direction is selected for the transmission of a signal from said first station to said second station. However, more than one beam directions can be
20 selected for the transmission of a signal from the first station to the second station. Preferably, two beam directions are selected for the transmission of a signal from said first station to said second station.

25 In certain embodiments the at least one direction for transmission is selected for a given time slot. However, the at least one direction for transmission can be selected for a given signal packet. Alternatively, the at least one direction for transmission is varied within a signal burst
30 such that the at least one direction for transmission is selected for a component part of a signal packet or a time slot.

In some embodiments, transmission direction can be selected by
35 a random selection step and a subsequent verification step. In other embodiments the at least one direction for transmission is selected from the set of feasible directions according to predetermined rules.

40 According to another aspect of the present invention there is provided apparatus for directional radio communication between

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5 a first station and a second station, the apparatus comprising means for determining a set of one or more directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station and means for selecting at said first
10 station at least one of said directions for transmission of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is controlled such that successive signals or groups of signals are transmitted in substantially different directions
15 and such that on average each beam direction available to said first station is used substantially equally.

According to a further aspect of the present invention there is provided a method of directional radio communication
20 between a first station and a second station, a plurality of directions being available for the first station to transmit to the second station, said method comprising the steps of selecting at the first station one or more of said plurality of directions for transmission from said first station to said
25 second station, said selection of one or more of said plurality of directions taking into account the traffic conditions in each of said plurality of directions.

Preferred methods and apparatus improve link quality because
30 they lead to improvements in spatial correlations between the uplink and downlink channels. Preferred methods also provide fast angular diversity and the efficient whitening of the generated co-channel interference. Methods embodying the invention have particular advantages in radio environments
35 characterised by large angular spreads and/or where base transceiver stations have relatively high angular resolutions.

A number of transmission direction selection schemes may be employed in various embodiments.

40

For a better understanding of the present invention and as to

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5 how the same may be carried into effect, reference will be made by way of example only, to the accompanying drawings in which:

Figure 1 is a schematic view of a base transceiver station and
10 its associated cell sectors;

Figure 2 is a schematic view of the base transceiver station of Figure 1;

15 Figure 3 is a schematic illustration of a first embodiment;

Figure 4 is an example of direction of arrival data;

Figure 5 is a more detailed representation of an uplink
20 communication burst;

Figure 6 is a representation of uplink and downlink communication bursts used in the embodiment of Figure 3; and

25 Figure 7 is a representation of uplink and downlink communication bursts used in a second embodiment.

Reference will first be made to Figure 1 which shows three cell sectors 2 of a cellular mobile telephone network. The
30 three cell sectors 2 are served by respective base transceiver stations (BTS) 4. Three separate base transceiver stations 4 are provided at the same location. Each BTS 4 has a transceiver which transmits and receives signals to and from a respective one of the three cell sectors 2. Thus, one
35 dedicated base transceiver station is provided for each cell sector 2. Each BTS 4 is thus able to communicate with mobile stations (MS) such as mobile telephones which are located in respective cell sectors 2.

40 Data is transmitted between the base station 4 and the mobile station in successive communication bursts. Each

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5 communication burst includes a reference signal which is a known sequence of data. The purpose of the reference signal is generally to allow information which assists operation of the system to be obtained by the receiving station. This type of information includes, for example, direction of arrival
10 information, signal strength information and delay information. In current GSM systems the reference signal is referred to as the training sequence, whereas in CDMA systems the reference signal corresponds to the pilot signal. Preferred embodiments will be described in the context of a
15 code division multiple access system which uses an antenna array at the base station. Each communication burst is transmitted in a given communication channel defined by the selected direction and the applied spreading code.

20 Figure 2 shows a schematic view of a base transceiver station 4 suitable for code/space division multiple access systems. The base station 4 only serves one of the three cell sectors 2 shown in Figure 1. Another two base stations 4 are provided to serve the other two cell sectors 2. It should be
25 appreciated that the various blocks illustrated in Figure 2 do not necessarily correspond to separate elements of an actual base transceiver station for performing the method of the present invention. The various blocks illustrated in Figure 2 correspond to various functions carried out by the base
30 transceiver station.

The base transceiver station 4 has an antenna array 6. In this example, the antenna array 6 has eight antenna elements. The elements are arranged to have a spacing of about a half
35 wavelength between each antenna element and are arranged in a horizontal row in a straight line. Each antenna element is arranged to transmit and receive signals and can have any suitable construction. Each antenna element may be a dipole antenna, a patch antenna or any other suitable antenna. The
40 eight antenna elements together define a phased antenna array 6.

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5 Each antenna element of the phased array antenna 6 is supplied with the same signal to be transmitted to a mobile station MS. However, the phases of the signals supplied to the respective antenna elements are shifted with respect to each other. The differences in the phase relationship between the signals
10 supplied to the respective antenna elements gives rise to a directional radiation pattern. The antenna array 6 can be controlled to provide a beam in one or more of the eight directions b_1 - b_8 illustrated. For example, the antenna array 6 could be controlled to transmit a signal to a MS only in the
15 direction of beam b_5 or only in the direction of beam b_6 or in more than one beam direction at the same time. Further, a signal may be transmitted in the two directions defined by beam b_5 and beam b_6 or in the three directions defined by b_1 , b_2 and b_4 .

20

The control and demodulation circuitry 8 includes beam forming circuitry such as Butler matrix circuitry, amplifier stages, analogue-to-digital converter arrays and digital to analogue converter arrays. In certain embodiments, digital beam
25 forming means are used instead of analogue beam forming means and these are implemented in the signal processing and decision block 10. In the receive direction, the beam forming circuitry detects the phase difference between each of the signals received by the respective antenna elements and uses
30 this information to determine the or each beam direction from which the signal has been received. Received signals are typically then passed through the amplifier stages to demodulation circuitry where the carrier frequency component is removed. The received analogue signal is converted to a
35 digital signal and is output to the signal processing and decision circuitry 10. In the transmit direction, the relative phase of the signal supplied to each antenna element and thus also the desired beam direction is controlled by the beam forming circuitry. Before being supplied to the antenna
40 elements digital data from the signal processing circuitry are converted to analogue signals and modulated onto the carrier

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5 frequency.

The signal processing and decision circuitry 10 despreads the received signal. The signal processing and decision circuitry determines the channel impulse response for the received
10 signals from which parameters used to define a channel for transmission of subsequent signals can be determined. The signal processing and decision circuitry 10 also carries out cross-correlation and analysis. Cross-correlation is used to generate taps which are representative of the channel impulse
15 response for that correlation and compares received signals and stored information. A channel impulse response is generated for each channel corresponding to a given communication burst received in each of the eight antenna directions b_1 - b_8 .

20 The analysis carried out within the signal processing and decision circuitry 10 is for determining and storing the maximum energy calculated from the channel impulse response. The signal processing and decision circuitry 10 also analyses
25 the channel impulse responses to ascertain the minimum delay with which a given signal is received. The channel with the minimum delay may represent the line of sight path between a mobile station and its base transceiver station.

30 Decision circuitry of the signal processing and decision circuitry 10 compares the determined parameters for each channel to determine transmission parameters for signals to be subsequently transmitted. The decision circuitry use a beam selection algorithm to select transmission parameters such as
35 beam direction and power level based on the information from the received signals. This selection can use simple methods such as selecting the beam direction(s) having the maximum energy and/or the minimum delay in the received signals. Alternatively, more complicated methods of selection may be
40 used.

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5 Figure 3 schematically illustrates a first embodiment. As shown in Figure 3, the base transceiver station receives an uplink communication stream 30 from a mobile station. The uplink communication stream 30 comprises a series of successive communication bursts in the $(i-1)$ th, i th and
10 $(i+1)$ th receive time slots, respectively. Each communication burst includes a pilot signal P and a data signal D. The pilot signal P includes a known sequence of data and is received in one or more specific directions of arrival. In the example of Figure 3, the pilot signal of the $(i-1)$ th time
15 slot is received in the directions b_1 and b_2 . The pilot signal of the i th time slot is received in the time slot b_1 , b_2 and b_3 . The pilot signal of the $(i+1)$ th time slot is received in the directions b_1 and b_3 . The signal processing and decision circuitry 10 of the base transceiver station 4
20 uses a beam selection algorithm 34 to determine which transmission directions to use for a given downlink communication time slot based on the directions in which the pilot signal P is received in the corresponding uplink communication burst and possibly also taking into account
25 information from previous time slots 36. In other embodiments, beam selection for transmission in the downlink communication slot is based on the directions in which the whole signal burst, i.e. both the pilot and data signals, are received.

30

For communication in the downlink direction the direction selected for transmission is varied from one communication burst to the next. Thus in this example a different downlink transmission direction is selected for each respective time
35 slot, whenever possible. For example, the signal burst (including the pilot and data signals) of the $(i+1)$ th downlink time slot is transmitted in a different direction to that used in the i th time slot. Similarly, the signal burst of the i th time slot is transmitted in a direction which is different to
40 that used in the $(i-1)$ th time slot. This is schematically illustrated in Figure 3 for the signal bursts of the downlink

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5 stream 32 by the directional antenna beams b_1 , b_2 and b_3 . In this example, the direction of transmission is changed from one time slot to the next and the pilot signal P and data signal D within a given time slot are transmitted in the same direction. However, this need not necessarily be the case.

10 The number of directions used may vary from time slot to time slot, as will be explained hereinafter.

The total number of selectable beam directions is typically a predetermined number which depends on the number of elements

15 in the antenna array. According to the general scheme of Figure 3 the base transceiver station 4 estimates an angular power profile upon reception of an uplink communication burst and using this information determines the directions of transmission to be used in the corresponding downlink

20 communication burst. This angular power profile is based on the received pilot signals P and includes direction of arrival information, an example of which is provided in Figure 4. In principal, any method for assessing the direction of arrival (DOA) could be employed to determine the set of feasible

25 transmission directions. An environment characterised by a large angular spread typically produces a number of different directions which are feasible for use in the downlink transmission direction. The power profile illustrated in Figure 4 shows estimated signal power (above a given threshold

30 Th) as a function of antenna beam direction measured in azimuthal angle of arrival.

According to the angular power profile of Figure 4 signals of appreciable strength, i.e. above the threshold Th , are

35 received in the antenna beam directions b_1 , b_2 and b_3 , with the signal of maximum energy being received from direction b_3 . This angular power profile could therefore correspond to the i th received time slot illustrated in Figure 3. The predetermined threshold Th is used to ensure that only

40 directions of arrival having appreciable signal strengths are taken into account. Any of the directions from which signals

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5 of appreciable strength are received can be regarded as feasible directions for transmission in the downlink direction.

10 Referring now to Figure 5, a set of feasible transmission directions S_i and the number of feasible directions n_i can be determined from the angular power profile determined from the pilot symbols of the i th received time slot. The number of feasible directions n_i corresponds to the number of directions from which signals are received which have a strength greater
15 than the predetermined threshold Th .

Thus, the set of feasible transmission directions S_i , may be represented as

$$20 \quad S_i = \{b_1, b_2, b_3 \dots b_x, b_{x+1}\} \quad (1)$$

where $b_1 \dots b_{x+1}$ are each feasible directions for transmission.

25 The receive communication stream 30 illustrated in Figure 5 shows three consecutive receive time slots, namely the $(i-1)$ th time slot, the i th time slot, and the $(i+1)$ th time slot. Each time slot comprises pilot symbols P and data D . Three sets of feasible transmission directions S_{i-1} , S_i and S_{i+1} are
30 generated in accordance with the angular power profiles determined from the pilot symbols of the $(i-1)$ th, i th and $(i+1)$ th receive time slots, respectively.

In general, n_i will depend upon the type of radio environment
35 and the average value of n_i would be expected to increase with the angular spread of the channel in question. The value of n_i is also dependent upon the spatial resolution of the base station (e.g. the number of separate antennas which make up the antenna array). The rate of change of the elements of the
40 set of feasible transmission directions S_i and its size n_i (i.e. the number of feasible directions) depends directly on

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5 the rate of change of the radio environment. In indoor environments, the number of feasible transmission directions determined from a given angular power profile might be say between 2 and 6, and once determined the set of directions can generally be used for relatively long periods of time (e.g.
10 say tens or hundreds of time slots).

The or each transmission direction is selected from the set of feasible transmission directions S_i . The set of transmission directions selected from the set of feasible directions S_i
15 will be referred to herein as T_i and the number of directions within that set as l_i . Preferred embodiments of the method of directional radio communication select, whenever possible, different beam directions for successive downlink signal transmissions. That is, whenever possible, a given signal
20 burst of the downlink communication stream is transmitted in substantially different direction to that used for the preceding signal burst. The manner of selection used for downlink transmission seeks on average to use all of the available directions an equal number of times. In the
25 embodiment described hereinafter in relation to Figure 6, a single beam direction is selected for transmission from the feasible directions (i.e. $l_i = 1V_i$). However, in other embodiments multiple directions are selected for transmission from the feasible directions (i.e. $l_i > 1V_i$). For example, in
30 the embodiment described hereinafter with reference to Figure 7 two beam directions are selected for transmission.

Referring to Figure 6, only one beam direction is selected for downlink transmission in each time slot and, whenever
35 possible, the direction selected is different to that selected for transmission in the preceding time slot. For the signal burst received in the (i-1)th time slot the set of feasible directions for transmission in the downlink direction is indicated as S_{i-1} . This set is determined from the angular
40 power profile of the pilot symbols P received in the (i-1)th time slot as described hereinbefore. The beam selection

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5 algorithm 34 which is provided with information on the transmission direction used in previous time slots then selects a beam direction to use for transmission in the corresponding downlink time slot. In this example, the direction $^{i-1}b_{nx}$ is selected for transmission in the
10 corresponding (i-1)th downlink time slot. It will be apparent that the set of feasible directions for downlink transmission must have contained the direction b_{nx} and it may or may not have contained other feasible transmission directions for the downlink communication.

15

For the signal burst received in the ith time slot the set of possible directions for transmission in the downlink direction is indicated as S_i . This set is determined from the angular power profile of the received pilot symbols of the ith receive
20 time slot. The beam selection algorithm 34 selects a beam direction to use for transmission in the corresponding downlink time slot based on the contents of the set S_i and with the knowledge that $^{i-1}b_{nx}$ was used as the transmission direction in the preceding downlink time slot. In this
25 example, the direction $^ib_{nx}$ is selected for transmission in the corresponding downlink ith time slot. It will be apparent that the set S_i of feasible directions for downlink transmission in the ith time slot contained the direction b_{nx} and may also have contained other feasible transmission
30 directions for the downlink communication. The downlink transmission direction b_{nx} was selected because it was a feasible direction as determined by the angular power profile and was a different direction to that used in the preceding downlink transmission slot. Had the set S_i contained only the
35 direction $^{i-1}b_{nx}$ then it would have been impossible to select a direction different to the downlink transmission direction used in the preceding (i-1)th time slot. This situation is explained in more detail later.

40 For the signal burst received in the (i+1)th time slot the set of feasible directions for transmission in the downlink

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5 direction is indicated as S_{i+1} . This set is determined from the angular power profile in the usual manner and is input to the beam selection algorithm 34 which is also provided with the knowledge that the direction ${}^i b_{nx}$ was used in the preceding
10 ith time slot. In this example, the set S_{i+1} of feasible directions for transmission in the downlink direction contains the direction ${}^{i+1} b_{nx}$ which was not used in the preceding ith time slot and this direction is selected for downlink transmission in the (i+1)th time slot.

15 The embodiment described with reference to Figure 6 can be expressed mathematically by defining the direction of transmission ${}^i b_{nx}$ for the ith time slot as follows

$${}^i b_{nx} \in S_i, \text{ and, whenever possible } {}^i b_{nx} \neq {}^{i-1} b_{nx} \quad (2)$$

20

where ${}^{i-1} b_{nx}$ and ${}^i b_{nx}$ are the beam directions selected in the (i-1)th and ith time slots respectively.

It should be appreciated that in certain circumstances a
25 directional hop will not be possible. That is, selection of a transmission direction which is different to that used in the preceding time slot will not be possible. For example, if the set of feasible transmission directions comprises only the direction corresponding to that used in the preceding slot.
30 This exception can be expressed mathematically as $S_i \neq {}^{i-1} b_{nx}$, where ${}^{i-1} b_{nx}$ is the transmission direction selected in the preceding time slot.

35 i.e. a beam hop will not be possible when the present set S_i has a unique element which is equal to the previously selected element.

Between them equation (2) and the above exception mean that,
40 whenever possible, two successive downlink signal bursts will be directed towards different angular positions within the

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5 cell or cell sector served by the base station.

To maximise the benefit from increased diversity, preferred embodiments seek on average to use all of the available directions of transmission b_1 - b_8 an equal number of times. Predetermined rules can control selections of the downlink transmission direction such that on average the cell or cell sector served by the base station is systematically and evenly illuminated. Preferably, the probability of transmitting in a given downlink transmission direction is constant and equal to $1/m$, where m is the total number of beam directions b_1 - b_8 available to the system. In this way, the density of interference is uniformly distributed over the area served by the base station. This is an efficient way of spatially whitening the interference generated. Examples of selection strategies are set out below:

Random Directional Hopping

The downlink transmission direction $i b_{nx}$ is selected from the set of feasible transmission directions S_i at random. This approach is effective, simple and thus easy to implement. A verification procedure can be used to reduce use of or avoid using altogether the same transmission direction in successive signal bursts (i.e. to avoid the condition $i b_{nx} = i^{-1} b_{nx}$). According to one such verification procedure, a new selection is carried out if it is determined that $i b_{nx} = i^{-1} b_{nx}$. This second random selection is performed and the beam selected in the second random selection is used whatever the result (i.e. even if $i b_{nx} = i^{-1} b_{nx}$ again). Limiting the number of selection and verification steps in this way can simplify implementation considerably. In other circumstances, the number of selection and verification steps may not be limited to one and in principle the number of such steps can be any number up to when $i b_{nx} \neq i^{-1} b_{nx}$.

Predetermined Directional Hopping Patterns

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5 Another example is where the downlink transmission direction ${}^i b_{nx}$ is selected from the set S_i according, whenever possible, to a predetermined directional hopping pattern designed to ensure that on average all of the available transmission directions are used equally. This category of selection
10 method includes spatial scanning strategies, three examples of which are provided below. In general such strategies seek to gradually scan through the plurality of beam directions available for downlink transmission by selecting from the feasible beam directions in a systematic manner. The area
15 served by the base station is divided into a plurality of directions which are arbitrarily numbered b_1 through b_g . The scanning process may involve for example, ascending (increasing), descending (decreasing) or ascending then descending through the plurality of feasible beam directions
20 contained in the set S_i .

In increasing spatial scanning, the downlink direction of transmission b_{nx} is selected such that ${}^i b_{nx}$ is substantially adjacent to ${}^{i-1} b_{nx}$ and of an incrementally higher value. Once
25 the maximum numbered direction has been reached the directional scanning process begins again from the minimum value direction available, and so on. That is, whenever possible, the direction of transmission b_{nx} is selected such that ${}^i b_{nx} \triangleright {}^{i-1} b_{nx}$ (where \triangleright indicates that ${}^i b_{nx}$ is the closest
30 possible beam direction in which ${}^i b_{nx} > {}^{i-1} b_{nx}$). Such a directional hopping process would thus seek to successively select from the feasible transmission directions by stepping through the feasible directions from the lowest value direction, returning to the lowest value direction to repeat
35 the scan in the same direction once the highest value direction has been reached.

In decreasing spatial scanning, the downlink direction of transmission ${}^i b_{nx}$ is selected starting at the highest value
40 direction such that ${}^i b_{nx}$ is substantially adjacent to ${}^{i-1} b_{nx}$ and of an incrementally lower value. Once the lowest value

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5 direction has been reached, the directional scanning process begins again from the maximum value direction available, and so on. That is, when ever possible, $^i b_{nx} < ^{i-1} b_{nx}$ (where $<$ indicates that $^i b_{nx}$ is the closest possible direction in which $^i b_{nx} < ^{i-1} b_{nx}$). This directional hopping process thus seeks to
10 successively select from the feasible transmission directions beginning at the highest value direction and stepping through to the lowest value direction, returning to repeat the scan in the same direction once the lowest value direction has been reached.

15

Increasing-decreasing spatial scanning is a combination of the increasing and decreasing methods, according to which the progressive spatial scanning incrementally shifts between two available extremes defined, at any point in time, by the set
20 of feasible directions. This type of directional hopping process seeks to successively select from the feasible transmission directions beginning say at the lowest value direction and stepping through to the highest value direction before reversing the direction of scanning once the highest
25 value direction has been reached.

In cases where the predetermined directional hopping pattern cannot be followed because the selection of transmission direction according to the pattern is the same as that in the
30 previous downlink signal burst (i.e. $^i b_{nx} = ^{i-1} b_{nx}$), a deviation from the pattern may be allowed. Rules can govern what happens when the predetermined patterns are deviated from. For example, in one embodiment the transmission direction is selected again at random. In another embodiment the violating
35 direction is simply omitted and the process thereafter continues according to normal procedure.

Another example of directional hopping according to a predetermined selection pattern is referred to herein as step
40 hopping. In this example, the downlink transmission direction is selected from the set of feasible directions to be,

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5 wherever possible, a direction which differs from the direction selected in the preceding signal burst by a given angular step $\pm \Delta b$. In this way, the selected downlink transmission direction alternates right-to-left and right again (etc) about the line of sight direction. Step hopping is
 10 useful, in particular, where fixed terminals operate in indoor cells. In a modified version of step hopping, the downlink transmission direction is selected from the feasible directions to be, wherever possible, a direction which differs from a reference direction by a given angular step $\pm \Delta b$. The
 15 reference direction may be checked and updated at intervals.

In both types of step hopping, the angular step $\pm \Delta b$ is preferably optimised to reduce or avoid the effect of accumulated interference towards a given direction. Such
 20 patterns can provide that the actual direction selected ${}^i b_{nx}$ alternates from one side of the previously used direction ${}^{i-1} b_{nx}$ (or the reference direction ${}^R b_{nx}$) to the other while maintaining the angular gap. That is, a given selection can be ${}^{(i-1)} b_{nx} + \Delta b$ (or ${}^R b_{nx} + \Delta b$) and the subsequent selection can
 25 be ${}^{(i-1)} b_{nx} - \Delta b$ (or ${}^R b_{nx} - \Delta b$), and so on.

The methods described hereinabove seek on average to evenly distribute the generated interference over the area of the cell or cell sector served by the base station.

30 In certain embodiments a generalisation of equation 2 may be applied, i.e.

$$\begin{aligned}
 & {}^i b_{nx} \in S_i \text{ and, whenever possible} \\
 & {}^i b_{nx} \neq {}^{i-1} b_{nx} \neq {}^{i-2} b_{nx}, \dots \neq {}^{i-N} b_{nx}
 \end{aligned}
 \tag{3}$$

Selection according to equation (3) improves spatial whitening further because it takes into account (and seeks to avoid) the directions used in the N previous signal bursts. It should be
 40 appreciated that the above spatial scanning methods seek by definition to fulfill equation (3).

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5 In some embodiments, additional traffic conditions are taken into account during beam selection for downlink transmission. These traffic conditions may also be used to determine the nature of the directional hopping scheme employed. The interference density in a particular direction, the relative
10 power loading conditions of the transmission branches, the allowed beam power and other traffic conditions, can all influence the direction which is selected for downlink transmission. One or more of such traffic conditions may be considered in combination with the directions used previously.

15 In implementations of such embodiments, each of the directions in the set of feasible directions S_i may be assigned a priority which is taken into account during the beam selection process. For example, priority information relating to each
20 of the feasible beam directions can be provided to the beam selection algorithm such that directions with higher priorities are selected in preference to those with lower priorities. Beam priority can be defined as a number which indicates a certain preference in the selection, e.g. when a
25 directional hop is due, the base station may select the direction with the highest numerical priority.

In one embodiment only the directions within the set of feasible directions S_i established based on direction of
30 arrival information are assigned priority ratings. In another embodiment all of the available directions are assigned a priority rating based on the or each criteria deemed relevant in the particular application.

35 If interference density in a particular direction is to be taken into account during the beam selection process, then contributions to the priority of a given direction will increase as the number of co-channel users employing that direction decreases, and vice versa.

40 If the allowed beam power (average power or instantaneous

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5 power) is to be taken into account during the beam selection process, the contributions to the priority of a given direction will increase as the power employed in that direction tends away from the maximum allowed (average or instantaneous) power, and vice versa.

10

Other traffic conditions can influence the desirability of a direction for downlink transmission. Equipment and/or network limitations may mean that traffic conditions effect the desirability of certain directions, traffic conditions may increase the possibility of component failure. For example, each transmitting antenna element of a transceiver station is connected to circuitry which is typically sensitive to the electrical loading conditions resulting from transmission to multiple users. For example, in many transceiver station configurations each transmitting antenna is connected to a power amplifier. The distribution of power across these power amplifiers depends upon the traffic conditions (e.g. the number of connected mobile stations) and is a critical issue because the loading conditions dictate important characteristics which the power amplifier are required to possess. When selecting a power amplifier for a given application it is necessary to consider the mean power requirements and also the maximum amount of power (peak power) it will be required to withstand. Peak power loading results when a given transmission branch (including the antenna and associated power amplifier) is selected to serve a large number of users simultaneously. It is necessary to select power amplifiers designed with correspondingly high crest factors CF ($CF = \text{Peak Power} / \text{Average Power}$). The design constraints can be relaxed if the electrical load can be evenly distributed between the available power amplifiers, thereby avoiding problematic power imbalances or high peak loads in any particular branch.

40 Thus, the beam selection algorithm may seek to maintain an even power distribution over the various transmission branches

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5 in use, that is, the beam selection algorithm is provided with
information on the power loading conditions of the
transmission branches resulting from all of the mobile
stations connected at the time. In such embodiments, the
downlink transmission direction is, whenever possible,
10 selected such that the new direction tends not to produce an
unbalanced power loading condition between the available
transmission branches. The beam selection algorithm may take
into account peak and/or average power loading conditions. As
an example, one such beam selection algorithm selects,
15 whenever, possible a downlink transmission direction which is
statistically unloaded. A given direction is more likely to
be selected for downlink transmission if it is different to
one or more directions used previously and the instantaneous
(and/or average) power loading is lower than in other
20 directions. In one such embodiment, the beam selection
algorithm only regards a direction as feasible for downlink
transmission if the power loading conditions indicate that the
instantaneous (and/or average) power loading conditions are
lower than in other directions. In another embodiment, the
25 beam selection algorithm only regards a direction as feasible
for downlink transmission if the instantaneous (and/or
average) power loading conditions are below a predetermined or
adaptively set threshold.

30 Such methods are effective because the interference generated
by the transmitted signal is spatially whitened and because
the method reduces the risk of hardware impairments or
failure. Using the example of power amplifiers, high peak
loads in a given power amplifier will be avoided and the
35 average power requirements for each power amplifier will be
substantially the same. Practical implementations which take
power loading conditions into account can monitor the bit-rate
(which is indicative of transmitted power) imbalance between
the various transmission branches in use. Thus, the higher
40 the bit-rate used in a given direction in relation to the bit
rate used in another directions, the lower is the contribution

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5 to priority of that direction.

The methods described thus far increase diversity using a single transmission beam by controlling the selection of transmission direction in the spatial (angular) regime. Such
10 methods become more effective as the angular spread of the radio environment and/or the resolution of the antenna array are increased. The methods described thus far make no attempts to increase diversity by increasing the number of beams transmitted.

15

Figure 7 illustrates an embodiment employing the selection of multiple transmission directions from the set of feasible directions (i.e. $l_i > 1V_i$). In the example of Figure 7, two downlink transmission directions are selected simultaneously.
20 The selection of two transmission beams instead of one provides a greater diversity gain than, for example, changing from the selection of three beams instead of two. At the same time, using a maximum of two downlink transmission beams limits the total amount of generated interference.

25

Referring to Figure 7, two beam directions are selected for downlink transmission in each time slot and, whenever possible, the directions selected are different to those used for transmission in the preceding time slots. For the signal
30 bursts received in the (i-1)th time slot, the set of feasible directions for transmission in the downlink direction is indicated as S_{i-1} . This set is determined from the angular power profile of the pilot symbols P received in the (i-1)th time slot as described hereinbefore. The beam selection
35 algorithm 34 which is provided with information 36 on the transmission direction used in previous time slots then selects two beam directions to be used for the transmission in the corresponding downlink time slot. In the (i-1)th time slot, the directions selected for downlink transmission are
40 $i^{-1}b_{mx}$ and $i^{-1}b_{nx}$. It will be apparent that the set S_{i-1} of possible directions for downlink transmission in the (i-1)th

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5 time slot would have contained the directions b_{mx} and b_{nx} and it may or may not have contained other feasible transmission directions for the return communication.

For the signal burst received in the i th time slot the set of
10 possible directions for transmission in the downlink direction is indicated as S_i . This set is determined from the angular power profile of the received pilot symbols of the i th receive time slot as above. The beam selection algorithm 34 selects two beam directions to use for transmission in the
15 corresponding downlink time slot based on the contents of the set S_i and on the knowledge of which two directions were used in the preceding $(i-1)$ th downlink time slot. In this example, the directions b_{mx} and b_{nx} are selected for transmission in the corresponding i th downlink time slot. It should be
20 appreciated that the set S_i of feasible directions for downlink transmission in the i th time slot contained the directions b_{mx} and b_{nx} and may also have contained other feasible transmission directions for the downlink communication. The directions b_{mx} and b_{nx} were selected
25 because they were feasible directions as determined in the angular power profile of the pilot symbols for the i th time slot and were different directions to those used in the preceding downlink transmission slot. However, had the set S_i contained only the directions b_{mx} and b_{nx} , then it would
30 have been unavoidable but to select those directions and thus the same transmission directions would have been used in the successive $(i-1)$ th and i th time slots.

For the burst received in the $(i+1)$ th time slot the set of
35 feasible directions for transmission in the downlink direction is indicated as S_{i+1} . This set is determined from the angular power profile in the usual manner and is input into the beam selection algorithm 34 which also knows which beam directions were used in the preceding i th time slot. In this example,
40 the set S_{i+1} of feasible directions for transmission in the downlink direction contains the directions b_{mx} and b_{nx}

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5 which were not used in the preceding i th time slot and which are selected for downlink transmission in the $i+1$ th time slot.

The double beam embodiment described in relation to Figure 7 can be expressed mathematically by defining the directions of
 10 transmission $i b_{mx}$ and $i b_{nx}$ ($i b_{mx}$ does not equal $i b_{nx}$) corresponding to the i th transmission slot as:

$$\{i b_{mx}, i b_{nx}\} \in S_i \text{ and, whenever possible,} \\ i b_{mx} \neq \{i-1 b_{mx}, i-1 b_{nx}\} \text{ and } i b_{nx} \neq \{i-1 b_{mx}, i-1 b_{nx}\} \quad (4)$$

15

It should be appreciated that in certain circumstances one or both of the directions $i b_{mx}$ and $i b_{nx}$ selected for downlink transmission may not differ from beam directions selected for transmission in the preceding downlink slot. That is,
 20 selection of transmission directions which are different to those used in the preceding time slot will not be possible if the set of feasible transmission directions comprises a limited number of feasible directions, one or more of which corresponding to a direction used in the preceding slot.
 25 These exceptions can be expressed mathematically as follows

$$S_i \neq \{i-1 b_{mx}, i-1 b_{nx}\}$$

As with the embodiment of Figure 6, selection of the downlink
 30 transmission direction can be governed by rules which seek on average to systematically and evenly illuminate the sector such that the probability of transmitting in a given direction b_1 to b_8 is constant (i.e. $1/M$ where M is the number of possible transmission directions available). In principle,
 35 strategies such as the random directional hopping strategies, the hopping strategies according to predetermined patterns, and directional hopping strategies according to stepped hopping patterns can be applied to the multi-beam transmission embodiment of Figure 7. For example, a random directional
 40 hopping strategy with a verification procedure to minimise use of corresponding directions in successive signal bursts can be

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5 used in conjunction with a multiple beam selection embodiment. Random beam selection methods will attempt to randomly select the two (or n directions to be used). Verifications can be done to check if repeated selections occurred as in the single beam case.

10

Increasing spatial scanning, decreasing spatial scanning and increasing-decreasing spatial scanning strategies and stepped scanning strategies can all be applied, *inter alia*, to the embodiment of Figure 7. Likewise, any additional criteria which influence the desirability of a direction for downlink transmission may be taken into account. For example, the allocation of priority ratings to directions based on traffic conditions can be applied, *inter alia*, to the embodiment of Figure 7.

20

It should be appreciated that the multi-beam embodiment of Figure 7 exploits diversity by ensuring the generated interference is spread evenly over the cell or cell sector served by the base station. However, multi-beam embodiments also gain diversity by using more than one beam transmission direction simultaneously, thus exploiting higher order angular diversity. As with the embodiment of Figure 6, the effectiveness of multi-beam embodiments increases as the angular spread of the environment and the resolution of the antenna array are increased.

30

The embodiment of Figure 7 changes the nature of the generated interference so as to cause less disturbance to other co-channel users. The total amount of generated interference is limited by imposing a maximum number of two transmission beams in any one signal burst. The reduced disturbance of co-channel users is a considerable advantage, particularly in multi-rate systems.

40

Figure 2 is only a schematic representation of the eight possible beam directions which can be achieved with the

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5 antenna array 6. In practice, however, there will in fact be an overlap between adjacent beams. In some embodiments of the present invention, the width of the beams can be varied as well as the number of beams which are provided to cover a given area. Future communication systems employing large
10 numbers of antennas will facilitate truly multi-beam transmission ($l_i > 1$) using narrower beams. However, with narrow beams, the amount of generated interference is not spatially spread as effectively as with larger beam widths, and embodiments of the present invention will thus provide
15 further advantages.

To maximise the effectiveness of multi-beam diversity gain the mobile station which receives the signal can be capable of resolving the signals corresponding to the different paths.
20 A frequency-selective radio environment can inherently provide signal separation at the receiver. In a flat-fading environment (e.g., an indoor cell) the means for separating the signals must be provided by the transmitter itself because otherwise signals from different beams will arrive with
25 similar delays. It follows therefore that in those cases, when transmitting with multiple beams ($l_i > 1$), artificial delays can be introduced in the corresponding transmitting branches such that the relative delays among the transmitted signals enable the receiver to separate the various signal
30 components. In fact, any suitable signal separation technique can be employed. For example in other embodiments, the signals from different beams could be separated by using different pilot sequences or spreading codes in each respective beam direction.

35 Thus preferred embodiments provide a method by which a base station can spatially whiten the generated interference by virtue of using directional hopping in the downlink transmission direction. Both single or multi-beam hopping
40 approaches can be used. Since the directions for downlink transmission are chosen from a set of feasible transmission

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5 directions determined from measuring parameters of the uplink communication stream, the downlink performance is better than that of conventional methods exploiting a single antenna element or beam. This method is therefore an efficient and reliable method for downlink transmission.

10

A plurality of different directional hopping strategies (for example random hopping, predetermined hopping, step hopping) are presented as examples of how selection of the downlink transmission direction can be controlled to ensure that the
15 cell or cell sector served by the base station is systematically and uniformly illuminated. Whenever possible, the information for a given user can be transmitted on a different beam (or beams) in each time slot. In the long term, the interference will be spatially averaged. This is
20 particularly beneficial in multi rate systems (e.g. in wide band code division multiple access WCDMA) systems where high bit rate users could even mask low bit rate users.

The directional hopping in the angular domain is (i) exploited
25 by the target user, even with a single antenna receiving station, as diversity which is seen as a decrease of desired signal outage probability and (ii) seen by each co-channel user as the time hopping interference source which has less probability of causing problems than a constant interference
30 source.

In modified versions of the method, the hopping patterns/selection rules could be defined as specific states. In such cases, state selection depends on channel
35 characteristics and past behaviour.

In another modified version, the method is extended to the case of packet data transfer. A packet will be equivalent to a time slot. Note that two consecutive time slots are usually
40 separated by a constant period of time while two successive packets may be separated by an indeterminate time period. In

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5 such modified versions, two consecutive packets will be transmitted, whenever possible, in different directions according to the selection characteristics of the particular embodiment.

10 In another modified version, the method is extended to the case of bitwise signal processing. According to this version, both the reference signal and data signal of a burst received in the uplink direction each comprise a succession of signal components referred to herein as bits. Likewise, communication
15 bursts transmitted in the downlink communication stream each include a reference signal and a data signal comprising a succession of signal components referred to herein as bits. Respective signal components, namely the respective signal bits, of the reference signal and/or the data signal are
20 transmitted, whenever possible, in substantially different directions as defined in relation to the embodiments described herein.

25 In another modified version, the directional hopping frequency may be reduced by, for example, hopping only after a predetermined number N of time slots (or signal bursts or signal components). Thus a different selection is made for successive groups of transmitted signals.

30

In the embodiments described herein, the directions of transmission for the downlink direction are selected based on the direction of arrival and the energy of the corresponding received signal in the uplink direction. However, any
35 suitable criteria can be used to determine the beam directions for transmission. For example, other embodiments take into account the minimum delay and/or the minimisation of generated interference in specific directions.

40 In another modified version, the receiving station (e.g. mobile station) makes or contributes to the selection of

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5 direction for downlink transmission. The receiving station may also determine the nature of the directional hopping scheme employed. This represents a type of closed-loop system as opposed to the open-loop systems considered hitherto.

10 The performance of the various embodiments described herein leads to improvements in correlations between the directions of arrival estimated from the uplink communications and the selection of transmission directions for the downlink channels.

15

In another modified version, signal bursts in a given direction are assigned a unique code which is orthogonal to other codes being used in the signal transmission. Referring to the i th time slot shown in Figure 7, a signal transmitted in the direction $i b_{mx}$ can be assigned a first code and signal transmitted in the $i b_{nx}$ direction can be assigned a second code, the first and second codes being orthogonal.

Embodiments of the invention can advantageously be used in
25 micro and/or pico cell environments, e.g. in indoor environments. Such radio environments not only carry large angular spreads but are also characterised by small delay spreads due to the small size of the environments. This is greatly beneficial, particularly in schemes exploiting
30 orthogonality (e.g. code orthogonality). It is also in these environments where high bit rate users can be expected.

Signals which are transmitted in the selected downlink direction may be multiplexed with respect to time, frequency,
35 space or spreading code. The different methods described hereinbefore can be used separately or in any combinations. Whilst embodiments of the present invention have been described in the context of a CDMA system, the present invention can be used with any other type of access system.

40

Methods illustrated with the downlink signal direction can be

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- 5 applied equally to the uplink signal direction provided the mobile station has means to implement the method. Embodiments of the present invention can be implemented in a mobile station as well as a base station.
- 10 The implementation should not be limited to the configurations of described embodiments. Specifically, the described embodiments show examples of configurations which may be used to implement the method and are not intended to define the only type, configuration or order of the apparatus features
- 15 which should be used.

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5 CLAIMS:

1. A method of directional radio communication between a first station and a second station, the method comprising the steps of:

10 determining at the first station a set of one or more directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station;

selecting at said first station at least one of said
15 directions for transmission of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is such that successive signals or groups of signals are transmitted in substantially different directions and such that on average
20 each beam direction available to said first station is used substantially equally.

2. A method as in claim 1, wherein the direction of transmission from said first station to said second station is
25 selected randomly from said set of feasible directions in a first random selection step.

3. A method as in claim 2, wherein a second selection is made from the set of feasible directions if the first
30 selection step selects a direction used in at least one preceding signal transmission.

4. A method as in claim 3, wherein a further random selection is made from the feasible directions if the second
35 random selection also indicates a direction used in at least one preceding signal transmission.

5. A method as in claim 3 or 4, wherein the direction selected is used whether or not it is the same as a direction
40 used in the at least one preceding signal transmission.

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5 6. A method as in claim 1, wherein the at least one direction for transmission is selected from the set of feasible directions according to predetermined rules.

10 7. A method according to claim 6, wherein the at least one direction for transmission is selected by selecting the next feasible direction to that used in the preceding transmission.

15 8. A method as in claim 7, wherein the selection process for successive transmissions steps through the set of feasible directions in a first direction.

20 9. A method as in claim 8, wherein the selection process for successive transmissions steps through the set of feasible directions in a second direction opposite to the first direction when a predetermined boundary is reached.

25 10. A method as in claim 6, wherein signals are transmitted such that the directions selected alternate respectively from one side of the preceding direction to the other side, at least a predefined angular spacing from said first direction being maintained in each instance.

30 11. A method as in claim 6, wherein a reference direction is defined and subsequent signals are transmitted such that the directions selected alternate respectively from one side of the reference direction to the other side, at least a predefined angular spacing from said reference direction being maintained in each instance.

35 12. A method as in any of claims 1 to 11, wherein the at least one direction for transmission is selected for a given signal burst in a code division multiple access system.

40 13. A method as in any of claims 1 to 11, wherein the at least one direction for transmission is selected for a given time slot in a time division multiple access system.

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- 5 14. A method as in any of claims 1 to 11, wherein the at least one direction for transmission is varied within a signal burst such that the at least one direction for transmission is selected for a component part of a signal packet or a time slot.
- 10 15. A method as in any preceding claim, wherein one beam direction is selected for the transmission of a signal from said first station to said second station.
- 15 16. A method according as in any of claims 1 to 14, wherein more than one beam directions are selected for the transmission of a signal from the first station to the second station.
- 20 17. A method according to claim 16, wherein two beam directions are selected for the transmission of a signal from said first station to said second station.
- 25 18. A method according to claim 1, wherein at least one direction is selected for successive groups of signals and each group of signals comprises a predetermined number of time slots.
- 30 19. A method according to claim 1, wherein at least one direction is selected for successive groups of signals and each group of signals comprises a predetermined number of signal packets.
- 35 20. A method according to claim 1, wherein at least one direction is selected for successive groups of signals and each group of signals comprises a predetermined number of component parts of a signal packet or a time slot.
- 40 21. A method according to any preceding claim when used in a network comprising a plurality of network elements comprising at least a plurality of said first and second stations, said

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5 selection step additionally taking into account at least one network criteria and/or at least one network element criteria.

22. A method as in claim 21, wherein the selection step takes into account interference density in one or more directions.

10

23. A method according to claim 21, wherein the selection step takes into account power loading conditions of components within said first station.

15

24. A method as in claim 23, wherein the selection step takes into account instantaneous power loading conditions of components within the first station.

20

25. A method as in claim 23, wherein the selection step takes into account average power loading conditions of components within the first station.

25

26. A method as in claim 23, wherein the selection step takes into account the bit-rates of multiple users connected to said first station.

30

27. A method according to any preceding claim, wherein the selection step takes into account the statistical loading of the or each direction.

35

28. A method according to any one of claims 21 to 27, wherein the selection step comprises allocating one or more directions a priority rating based on additional criteria taken into account, said selection step favouring directions with highest priority.

40

29. A method as in claim 28, wherein directions which have a low statistical use are allocated a greater priority than directions which have a relatively high statistical use.

30. A method as in any preceding claim, wherein said second

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5 station at least influences the selection made by the first station.

31. A method as in any preceding claim, wherein said first station is a base station.

10

32. A method as in any preceding claim, wherein said second station is a mobile station.

33. A method of directional radio communication between a first station and a second station, the method comprising the steps of:

determining at the first station a set of one or more directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station;

selecting at said first station at least one of said directions for transmission of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is such that successive signals or groups of signals are transmitted in substantially different directions and such that on average each beam direction available to said first station is used a substantially equally number of times.

34. Apparatus for directional radio communication between a first station and a second station, the apparatus comprising: means for determining a set of one or more directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station; and

means for selecting at said first station at least one of said directions for transmission of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is controlled such that successive signals or groups of signals are transmitted in substantially different directions and such that on average

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5 each beam direction available to said first station is used substantially equally.

35. A method of directional radio communication between a first station and a second station, a plurality of directions
10 being available for the first station to transmit in to the second station, said method comprising the steps of:

selecting at the first station one or more of said plurality of directions for transmission from said first station to said second station, said selection of one or more
15 of said plurality of directions taking into account the traffic conditions in each of said plurality of directions.

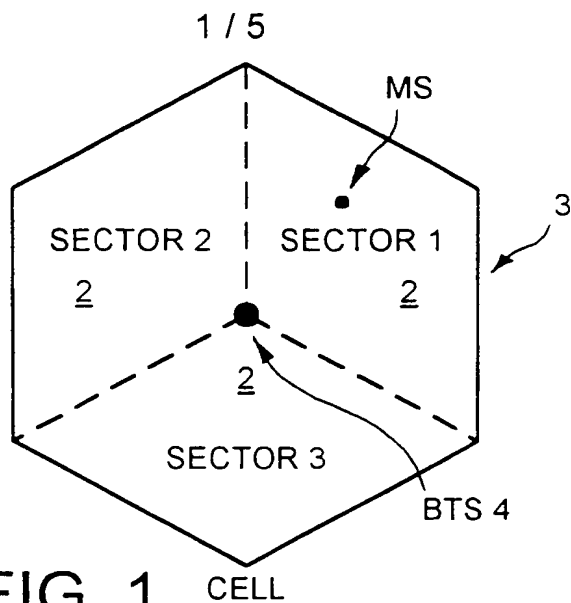


FIG. 1

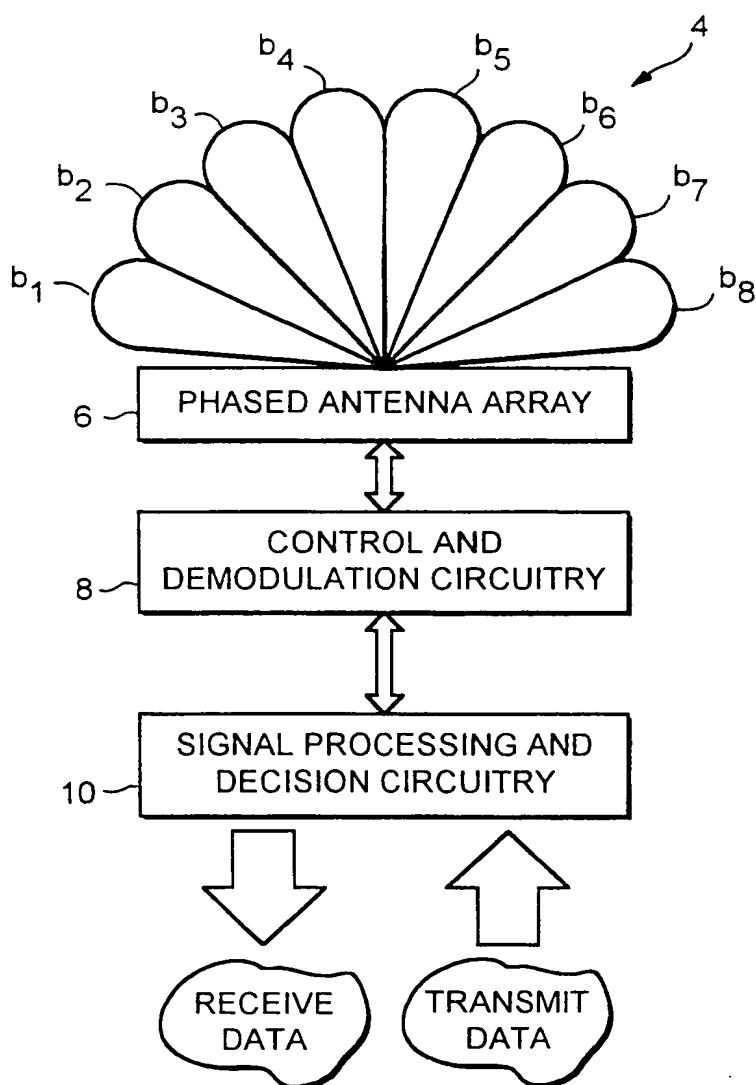


FIG. 2

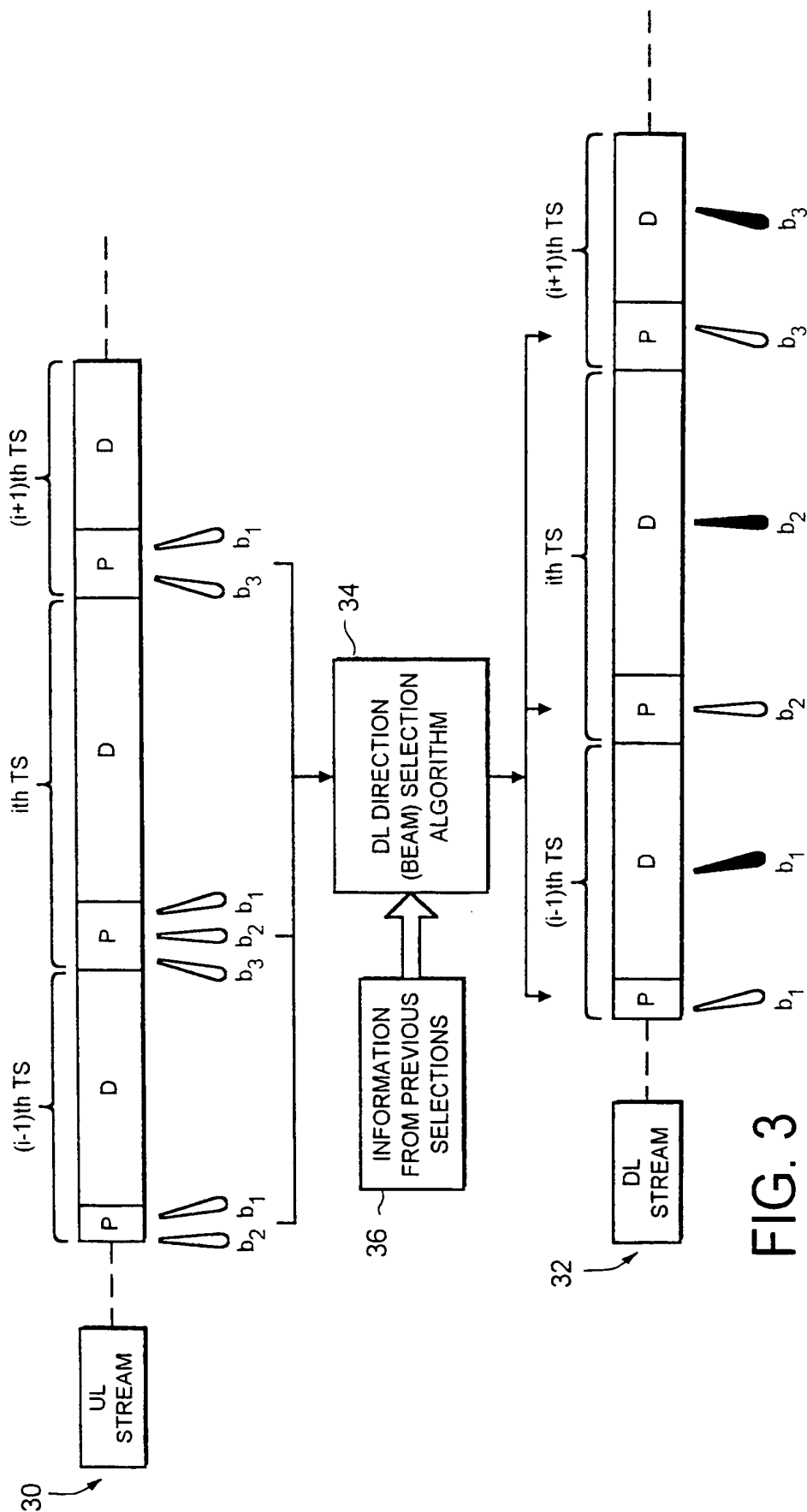


FIG. 3

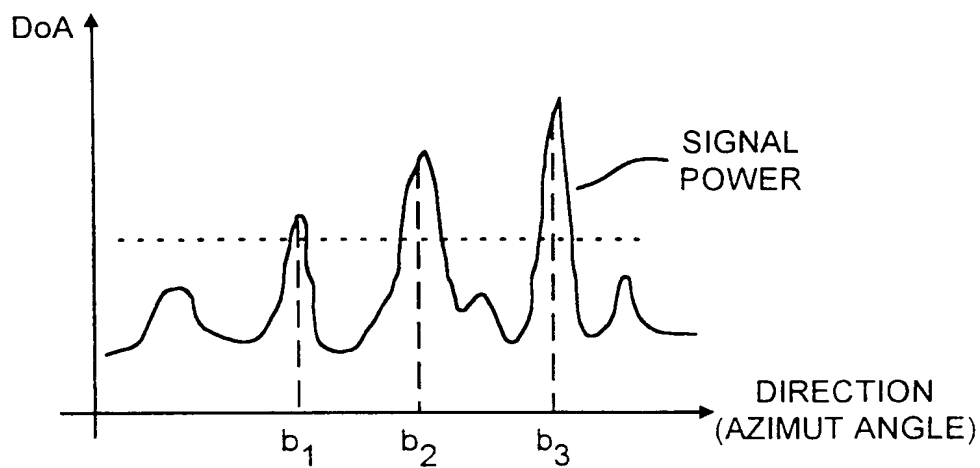


FIG. 4

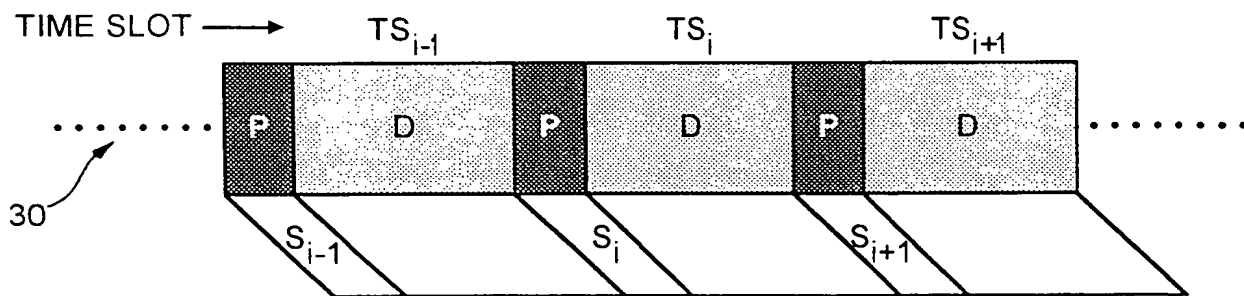


FIG. 5

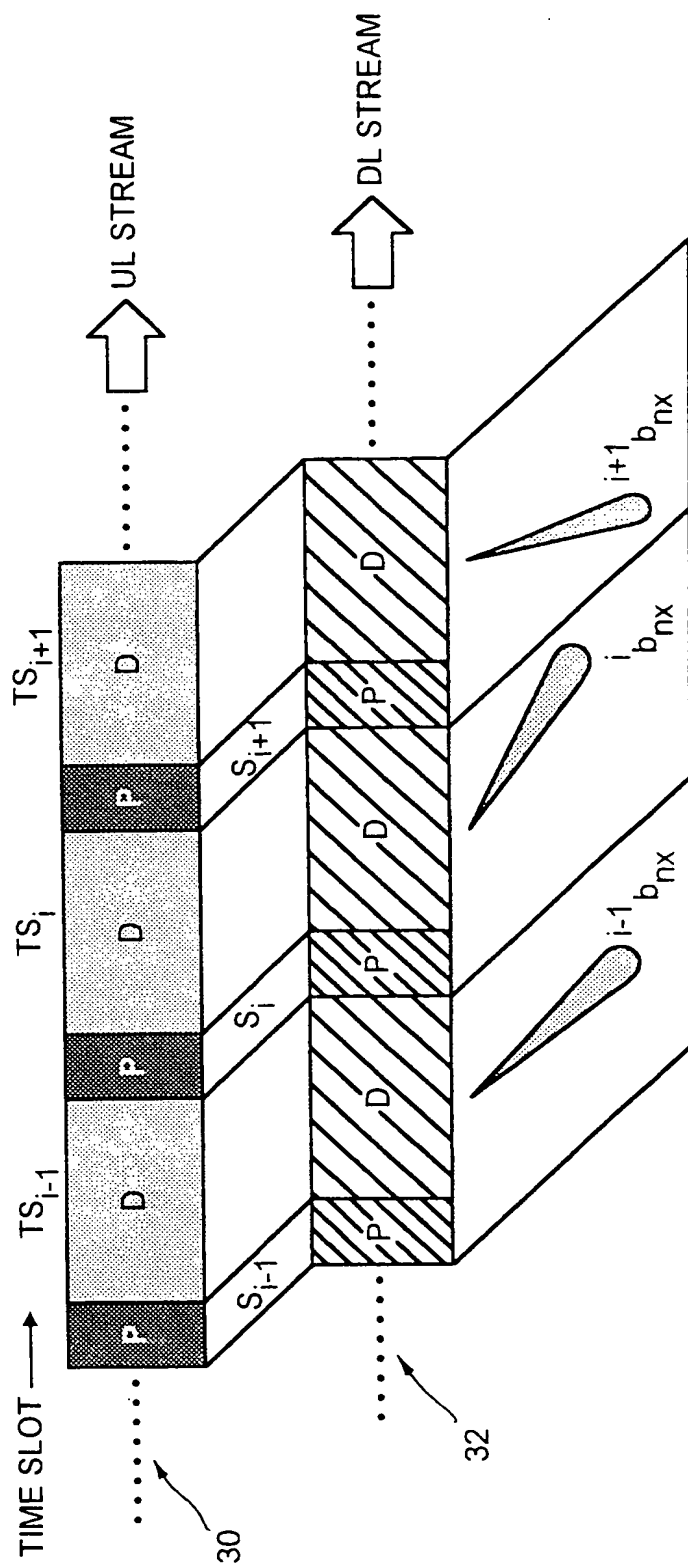
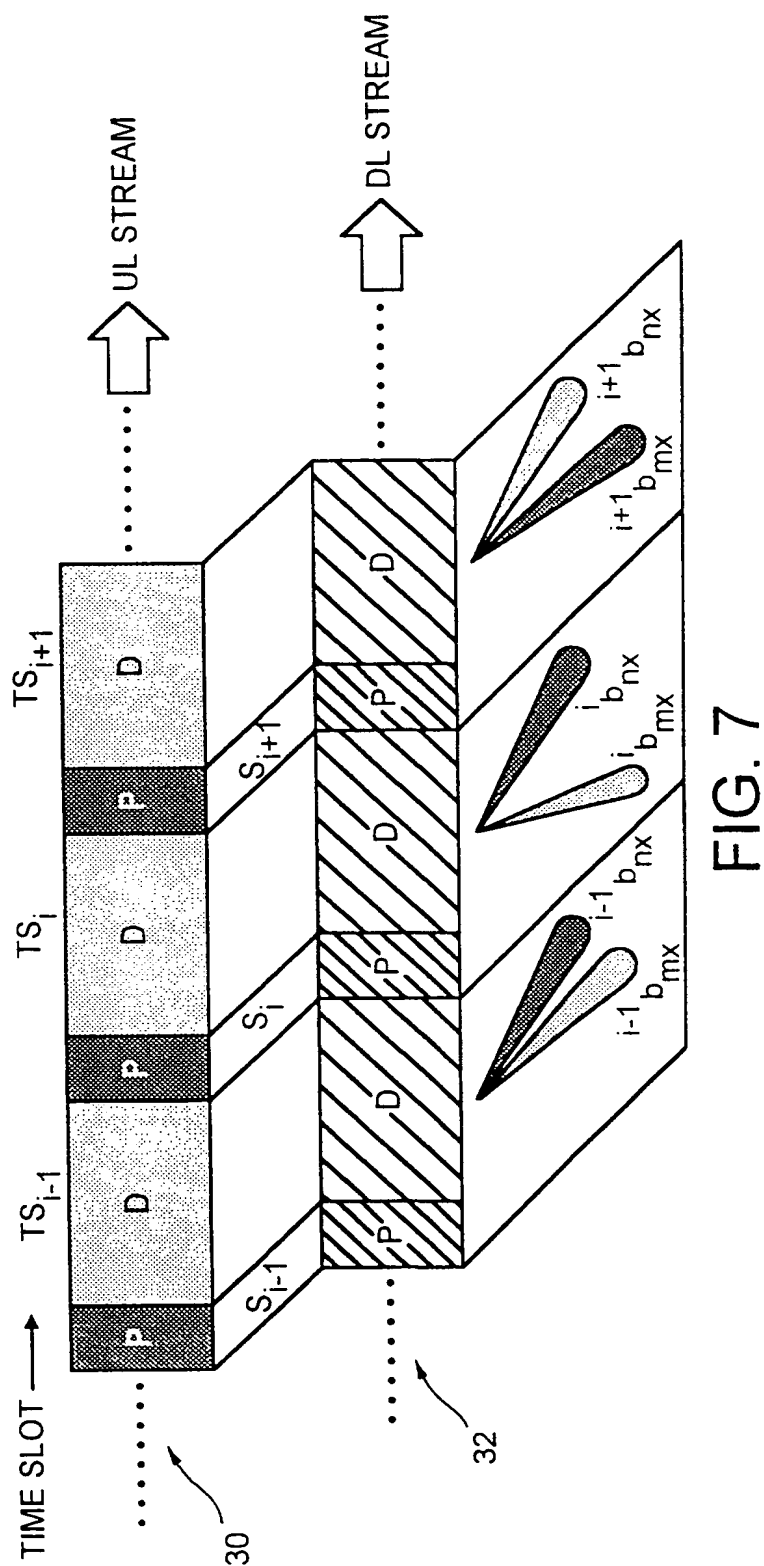


FIG. 6



INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 99/06778

A. CLASSIFICATION OF SUBJECT MATTER IPC 7 H04Q7/36		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) IPC 7 H04Q		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 37969 A (NOKIA TELECOMMUNICATIONS OY ;JOLMA PETRI (FI); KESKITALO ILKKA (FI) 28 November 1996 (1996-11-28) page 6, line 1 - line 20	1-7, 10-13, 15,30-35
A	page 12, line 24 -page 17, line 14 page 22, line 19 -page 23, line 21 page 24, line 17 -page 25, line 4 page 27, line 14 -page 28, line 9 page 29, line 7 -page 31, line 18 ---	14,16-20
X	WO 98 25362 A (MOTOROLA INC) 11 June 1998 (1998-06-11)	1-8,12, 15,30, 33,34
A	page 6, line 26 -page 9, line 7 page 10, line 6 -page 12, line 3 claims 1-10; figures 1-3 -----	13,14, 18-20, 22,31,32
<div style="display: flex; justify-content: space-between;"> <input type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex. </div>		
* Special categories of cited documents :		
<div style="display: flex;"> <div style="flex: 1;"> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="flex: 1;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>		
Date of the actual completion of the international search <div style="text-align: center; font-weight: bold;">17 January 2000</div>		Date of mailing of the international search report <div style="text-align: center; font-weight: bold;">24/01/2000</div>
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040. Tx. 31 651 epo nl. Fax: (+31-70) 340-3016		Authorized officer <div style="text-align: center; font-weight: bold;">Coppieters, S</div>

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/EP 99/06778

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
W0 9637969 A	28-11-1996	FI 952534 A	25-11-1996
		AU 707124 B	01-07-1999
		AU 5820696 A	11-12-1996
		CN 1157067 A	13-08-1997
		EP 0772918 A	14-05-1997
		JP 10503910 T	07-04-1998
		NO 970299 A	20-03-1997
		US 5966670 A	12-10-1999
W0 9825362 A	11-06-1998	US 5960350 A	28-09-1999
		AU 5160998 A	29-06-1998
		DE 19782178 T	18-11-1999
		FI 991274 A	03-06-1999
		FR 2757004 A	12-06-1998
		GB 2335575 A	22-09-1999

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)



Applicant's or agent's file reference 91725/KCS/JJH/ms	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/EP99/06778	International filing date (day/month/year) 14/09/1999	Priority date (day/month/year) 01/05/1999
International Patent Classification (IPC) or national classification and IPC H04Q7/36		
Applicant NOKIA NETWORKS OY et al.		



1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 4 sheets, including this cover sheet.

☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

 These annexes consist of a total of 9 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 11/07/2000	Date of completion of this report 07.08.2001
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Schweitzer, J-C Telephone No. +49 89 2399 8963 

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/EP99/06778

I. Basis of the report

1. With regard to the **elements** of the international application (*Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17)*):

Description, pages:

1-4,8-33	as originally filed	
5-7	with telefax of	15/06/2001

Claims, No.:

1-34	with telefax of	15/06/2001
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Drawings, sheets:

1/5-5/5	as originally filed
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2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/EP99/06778

- ☐ the description, pages:
☐ the claims, Nos.:
☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1 - 34
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1 - 34
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1 - 34
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Concerning section V.2 (reasoned statement under Article 35(2) PCT)

Claim 1 relates to a method for determining in a radio communications system at a first station a set of beam directions which are feasible for use in transmitting a signal from the first station to a second station and selecting a transmission beam direction from said set, such that successive signals are transmitted in substantially different directions and such that on average each beam direction is used a substantially equal number of times.

Such a method for selecting different beam directions for successive signals suitable to be used in code/space division multiple access systems is neither taught, nor rendered obvious, alone or in combination, by the prior art documents cited in the International Search Report. The cited **WO-A-96/37969 (Nokia)** merely teaches a method for determining at a base station beam directions ("angles of arrival") which are feasible for transmitting a signal to a mobile station and then selecting a transmission beam direction from said set of incoming directions, whereby the selected beam direction can be changed by small angles, e.g. to avoid fading, without any incentive for the skilled person to arrive at the present invention.

Claim 1 is therefore novel and considered to involve the required inventive step, Articles 33(2) and (3) PCT. The subject-matter of claim 1 is also industrially applicable.

The same applies to independent apparatus claim 34, which is drafted in structural terms and corresponds essentially to method claim 1. Claim 34, therefore, equally meets all the requirements of Article 33 PCT.

Dependent claims 2 to 33 relate to further implementing details of the method defined by claim 1 to which they refer and are thus equally novel, inventive and industrially applicable.

Concerning section VII (form and contents).

In order to meet the requirements of Rule 5.1.(a),(ii) PCT, the relevant prior art document noted above should be acknowledged by reference and briefly discussed in the introductory part of the description.

The claims do not include reference signs in parentheses where features shown in the drawings are referred to, Rule 6.2.(b) PCT.

-5-

In a low mobility environment (e.g. an indoor cell) the physical radio environment will tend to remain unchanged for a considerable amount of time and thus the direction(s) of transmission selected for each mobile station will be kept the same for relatively long periods. In multi-rate environments, this approach can generate undesirably high levels of spatially coloured interference. In other words, the background interference varies across the cell. For example, a base station serving a fixed or slowly moving high bit rate user operating in a pico-cell (i.e. a small cell) will select a few (e.g. two) directions of transmission based on the best received signal paths. In addition, to provide signals to the target high bit rate mobile station, the base station also produces high powered interference in the selected directions. Low bit rate users operating within the corresponding illuminated area will clearly be affected by this cross-correlation type of interference. The degrading effect of the interference is intensified by the fact that interfering signal tends to stay unchanged in the spatial (and delay) domain and consequently no averaging can be exploited by the receiver.

Thus in indoor environments, and in other environments where the angular spread is large and/or the user mobility is low, a conventional base station using adaptive antennas will tend to generate highly coloured interference when transmitting in the downlink direction. The spatial directions employed by high bit rate users tend to contain signals at high levels of transmitted power and thus affect lower bit rate co-channel users.

Embodiments of the present invention seek to provide an improved method for directional radio communication.

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Emfängerseit 15. Mai 1990

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According to an aspect of the present invention there is provided a method of directional radio communication between a first station and a second station, the method comprising the steps of determining at the first station a set of one or more
5 directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station, selecting at said first station at least one of said directions for transmission of a signal from said first station to said second station, wherein
10 the selection of the at least one direction for transmission is such that successive signals or groups of signals are transmitted in substantially different directions and such that on average each beam direction available to said first station is used a substantially equally number of times.

15 In one embodiment one beam direction is selected for the transmission of a signal from said first station to said second station. However, more than one beam directions can be selected for the transmission of a signal from the first
20 station to the second station. Preferably, two beam directions are selected for the transmission of a signal from said first station to said second station.

In certain embodiments the at least one direction for
25 transmission is selected for a given time slot. However, the at least one direction for transmission can be selected for a given signal packet. Alternatively, the at least one direction for transmission is varied within a signal burst such that the at least one direction for transmission is
30 selected for a component part of a signal packet or a time slot.

In some embodiments, transmission direction can be selected by a random selection step and a subsequent verification step.
35 In other embodiments the at least one direction for

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transmission is selected from the set of feasible directions according to predetermined rules.

According to another aspect of the present invention there is
5 provided apparatus for directional radio communication between
a first station and a second station, the apparatus comprising
means for determining a set of one or more directions which
are feasible for use in transmitting a signal from said first
station to said second station using a signal received from
10 said second station and means for selecting at said first
station at least one of said directions for transmission of a
signal from said first station to said second station, wherein
the selection of the at least one direction for transmission
is controlled such that successive signals or groups of
15 signals are transmitted in substantially different directions
and such that on average each beam direction available to said
first station is used a substantially equally number of times.

Preferred methods and apparatus improve link quality because
20 they lead to improvements in spatial correlations between the
uplink and downlink channels. Preferred methods also provide
fast angular diversity and the efficient whitening of the
generated co-channel interference. Methods embodying the
invention have particular advantages in radio environments
25 characterised by large angular spreads and/or where base
transceiver stations have relatively high angular resolutions.

A number of transmission direction selection schemes may be
employed in various embodiments.

30

For a better understanding of the present invention and as to

35

-34-

CLAIMS:

1. A method of directional radio communication between a first station and a second station, the method comprising the
5 steps of:

determining at the first station a set of one or more beam directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station;

10 selecting at said first station at least one of said beam directions for transmission of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is such that successive signals or groups of signals are transmitted in
15 substantially different directions and such that on average each beam direction available to said first station is used a substantially equal number of times.

2. A method as in claim 1, wherein the direction of
20 transmission from said first station to said second station is selected randomly from said set of feasible directions in a first random selection step.

3. A method as in claim 2, wherein a second selection is
25 made from the set of feasible directions if the first selection step selects a direction used in at least one preceding signal transmission.

4. A method as in claim 3, wherein a further random
30 selection is made from the feasible directions if the second random selection also indicates a direction used in at least one preceding signal transmission.

5. A method as in claim 3 or 4, wherein the direction
35 selected is used whether or not it is the same as a direction

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Empfangen am 15. Juni 1990

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used in the at least one preceding signal transmission.

6. A method as in claim 1, wherein the at least one direction for transmission is selected from the set of
5 feasible directions according to predetermined rules.

7. A method according to claim 6, wherein the at least one direction for transmission is selected by selecting the next feasible direction to that used in the preceding transmission.

10

8. A method as in claim 7, wherein the selection process for successive transmissions steps through the set of feasible directions in a first direction.

15 9. A method as in claim 8, wherein the selection process for successive transmissions steps through the set of feasible directions in a second direction opposite to the first direction when a predetermined boundary is reached.

20 10. A method as in claim 6, wherein signals are transmitted such that the directions selected alternate respectively from one side of the preceding direction to the other side, at least a predefined angular spacing from said first direction being maintained in each instance.

25

11. A method as in claim 6, wherein a reference direction is defined and subsequent signals are transmitted such that the directions selected alternate respectively from one side of the reference direction to the other side, at least a
30 predefined angular spacing from said reference direction being maintained in each instance.

12. A method as in any of claims 1 to 11, wherein the at least one direction for transmission is selected for a given
35 signal burst in a code division multiple access system.

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Empfangszeit 15. Juni 16.10

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13. A method as in any of claims 1 to 11, wherein the at least one direction for transmission is selected for a given time slot in a time division multiple access system.

5

14. A method as in any of claims 1 to 11, wherein the at least one direction for transmission is varied within a signal burst such that the at least one direction for transmission is selected for a component part of a signal packet or a time slot.

10

15. A method as in any preceding claim, wherein one beam direction is selected for the transmission of a signal from said first station to said second station.

15

16. A method according as in any of claims 1 to 14, wherein more than one beam directions are selected for the transmission of a signal from the first station to the second station.

20

17. A method according to claim 16, wherein two beam directions are selected for the transmission of a signal from said first station to said second station.

25 18. A method according to claim 1, wherein at least one direction is selected for successive groups of signals and each group of signals comprises a predetermined number of time slots.

30 19. A method according to claim 1, wherein at least one direction is selected for successive groups of signals and each group of signals comprises a predetermined number of signal packets.

35 20. A method according to claim 1, wherein at least one

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direction is selected for successive groups of signals and each group of signals comprises a predetermined number of component parts of a signal packet or a time slot.

- 5 21. A method according to any preceding claim when used in a network comprising a plurality of network elements comprising at least a plurality of said first and second stations, said selection step additionally taking into account at least one network criteria and/or at least one network element criteria.
- 10 22. A method as in claim 21, wherein the selection step takes into account interference density in one or more directions.
- 15 23. A method according to claim 21, wherein the selection step takes into account power loading conditions of components within said first station.
- 20 24. A method as in claim 23, wherein the selection step takes into account instantaneous power loading conditions of components within the first station.
- 25 25. A method as in claim 23, wherein the selection step takes into account average power loading conditions of components within the first station.
26. A method as in claim 23, wherein the selection step takes into account the bit-rates of multiple users connected to said first station.
- 30 27. A method according to any preceding claim, wherein the selection step takes into account the traffic conditions the or each direction.
- 35 28. A method according to any preceding claim, wherein the selection step takes into account the statistical loading of

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Emfängerseit 15. Juni 1990

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the or each direction.

29. A method according to any one of claims 21 to 28, wherein the selection step comprises allocating one or more directions
5 a priority rating based on additional criteria taken into account, said selection step favouring directions with highest priority.

30. A method as in claim 29, wherein directions which have a
10 low statistical use are allocated a greater priority than directions which have a relatively high statistical use.

31. A method as in any preceding claim, wherein said second
15 station at least influences the selection made by the first station.

32. A method as in any preceding claim, wherein said first station is a base station.

20 33. A method as in any preceding claim, wherein said second station is a mobile station.

34. Apparatus for directional radio communication between a first station and a second station, the apparatus comprising:
25 means for determining a set of one or more beam directions which are feasible for use in transmitting a signal from said first station to said second station using a signal received from said second station; and

means for selecting at said first station at least one of
30 said beam directions for transmission of a signal from said first station to said second station, wherein the selection of the at least one direction for transmission is controlled such that successive signals or groups of signals are transmitted in substantially different directions and such that on average
35 each beam direction available to said first station is used a

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Enfänger: 15. Juni 10.10

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substantially equal number of times.

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Empfangszeit 15 Juni 16:10

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 91725/KS/JH	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/EP 99/ 06778	International filing date (day/month/year) 14/09/1999	(Earliest) Priority Date (day/month/year) 01/05/1999
Applicant NOKIA TELECOMMUNICATIONS OY et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 2 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

- a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

- b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. ☐ **Certain claims were found unsearchable** (See Box I).

3. ☐ **Unity of invention is lacking** (see Box II).

4. With regard to the **title**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No.

☐ as suggested by the applicant.

☒ because the applicant failed to suggest a figure.

☐ because this figure better characterizes the invention.

7
☐ None of the figures.